INFRASENSE, Inc.

Ground Penetrating Radar (GPR) Analysis
RFP # HWY-308813-RP

Submitted by

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A. PROBLEM STATEMENT

Based on the RFP's Project Description, the Montana Department of Transportation (MDT) is aware of the potential benefits of using Ground Penetrating Radar (GPR) as a tool for evaluating pavement thickness and layer structure. MDT's implementation of GPR measurements in conjunction with its FWD data collection indicates the perceived value of combining GPR layer thickness data with FWD data for more accurate characterization of pavement structural properties. The objective of the proposed program is to assist the MDT in expanding its implementation of GPR technology to serve as an aid in the determination of reconstruction and rehabilitation treatments. In order to achieve this objective, it is necessary to understand:

(a) the types of layer structure information that GPR is capable of obtaining;

(b) the level of accuracy associated with this information under different pavement conditions;

(c) the use of this information in the selection and design of reconstruction and rehabilitation treatments; and

(d) the influence of the expected accuracy on the design and selection of reconstruction and rehabilitation treatments.

For example, the thickness variability within a given pavement section as well as the ability to differentiate between sections (i.e., a 5 inch AC over an unbound base that is adjacent to a 6.5 inch AC on a bound base) are critical inputs to any rehabilitation design. The accuracy with which GPR can provide this information will determine its value for this application.

In order to address this problem, the proposed program must integrate a detailed knowledge of the capabilities and limitations of GPR with the information needs of the MDT. The program will include characterization of the types of pavement construction and environmental conditions present within the state, and a detailed evaluation of the capabilities and limitations of GPR to provide useful information in these conditions. The program will also address the types of reconstruction and rehabilitation treatments employed by the MDT, and identify if, when, and how GPR data can serve as an aid in selecting the most appropriate treatment.

To achieve these project objectives, we have combined expertise and experience with both GPR applications to pavement, and with pavement evaluation, rehabilitation and reconstruction design. Infrasense, the prime consultant proposed for this work, has 20 years of experience in application of GPR to pavement structure evaluation. Infrasense has surveyed over 18,000 lane miles of pavement with GPR, and has carried out GPR pavement research studies for the SDDOT, IDT, WTD, and other state and federal agencies. Infrasense has worked with all types of GPR systems and antennas, and in particular has worked extensively with the GSSI SIR-20 system and model 4105 antenna currently used by MDT. The proposed principal investigator, Dr. Ken Maser, is an internationally known expert in GPR applications to pavements. For this project, Infrasense has teamed with Nichols Consulting Engineers (NCE). NCE has worked with Montana DOT to collect performance monitoring data at Long Term Pavement Performance (LTPP) test sections throughout the state, and is recognized throughout the pavement community for its expertise—particularly as related to research, pavement management and pavement design.

B. BACKGROUND SUMMARY

B.1 Background

Originally developed for geotechnical evaluations and mine detection, GPR was introduced for highway applications in the early 1980's. Some initial highway applications, such as detection of voids under joints in concrete pavements, were over-promoted and not particularly successful. In the late '80s and early '90's, application of GPR for assessment of highway pavement was researched in further depth, and the capabilities and limitations of the technology became better understood. Work by the New England Transportation Consortium (Maser, 1990) and the Ontario Ministry of Transport (Chung, 1991) demonstrated the capability of GPR for measuring the thickness of asphalt overlays on concrete decks. Subsequent work carried out jointly by Infrasense and Texas Transportation Institute (TTI) established the ability and accuracy of measuring GPR for the thickness of bound AC and unbound aggregate base layers (Maser and Scullion, 1992a), and for distinguishing the thickness of individual AC layers within the pavement structure (Maser and Scullion, 1992b). GPR application to measurement of pavement thickness has since become a subject of ongoing study by universities and research institutes, and GPR evaluation studies have been carried out by over 15 highway agencies (see Table 1). As a result, GPR has become a mainstream technology, with increasingly more routine use by highway agencies.

Table 1 (see Section D.2) summarizes the results of numerous GPR layer thickness validation and accuracy studies that have been carried out over the past 17 years by multiple highway agencies. These studies have shown that the level of accuracy in the GPR thickness measurement depends on the type of pavement structure and on the degree of calibration used. These thickness studies generally compare GPR thickness values to pavement core thickness values, and the differences have generally ranged from 2 – 10%. The variation is typically lowest for newer pavement, and highest for old pavement. Sometimes, the discrepancy in an older pavement is due to the fact that portions of the cores are not fully extracted (Maser, 2006). Some studies have also been carried out to investigate use of GPR for identification of moisture damage and stripping (Rmeili and Scullion, 1997, Maser and Mallick, 2006; Hammons et. al., 2005). These have shown that GPR can serve as a screening method for identification of the possibility of stripping, but other more local methods (e.g., seismic, coring) are needed to confirm that these areas are actually stripped.

Studies have demonstrated the use of calibration cores to help improve the accuracy of GPR, and studies that have used this calibration generally have more accurate correlation with core data that was not used for calibration (Maser, 2004; Al Qadi et. al., 2005). Experience has shown, however, that cores can even be more important in clarifying pavement layer type. For example, sometimes when the GPR data shows multiple layers, it is not always clear which layer boundary is the one between the bound and unbound material. This distinction can have a large impact on the interpretation of the GPR thickness data.

In practical applications over the past 10 years, GPR data has been used for rehabilitation design, FWD backcalculation, and pavement management. The Oklahoma and Utah DOT's have recently conducted statewide GPR surveys for pavement management purposes. In the Oklahoma Project (Williams et. al., 2005), GPR data was analyzed at FWD test locations over 3500 lane-miles to provide back-calculation information at a network level. In the Utah project, GPR data was collected on 2000 lane-miles of pavement strictly to characterize the uniformity of structure for the PMS (Maser and Vandre, 2006). At the project level, GPR has been used routinely to characterize pavement layer thickness for rehabilitation design. GPR pavement thickness data has been used for design of overlay thickness, and for use in back-calculating layer moduli. GPR thickness data has also been investigated for setting of milling depths for recycled asphalt pavement projects using PMRAP and foamed AC (Mallick et. al. 2007), and for process-in-place applications. Currently, GPR is being explored for providing thickness and density QA of new pavement construction. (Maser et. al, 2003; Sebesta and Scullion, 2003).

B.2 Summary of Proposed Approach

The Infrasense/NCE team approach is to investigate, demonstrate, and evaluate all possible applications of GPR to the reconstruction and rehabilitation of MDT's pavements. In order to achieve this objective, we propose the following approach:

- Categorize the pavement structure types and environmental conditions found in Montana;
- Review the reconstruction and rehabilitation practices currently used by MDT;
- Identify the type of *in-situ* pavement structure information that is needed to optimally implement these practices;
- Assess the capabilities and limitations of GPR to provide the desired information under the range of structure types and environmental conditions found in Montana. This assessment will initially utilize a review of existing literature and previous testing, and will ultimately include the results of testing to be conducted at selected sites in Montana. The selected sites will be based on a test matrix which incorporates the range of MDT's pavement structure types and environmental conditions;
- Statistically evaluate the data collected on the Montana sites to characterize the accuracy and confidence level provided by the GPR data in determining the necessary information;
- Using the established accuracies and confidence levels, conduct a sensitivity study to evaluate the potential benefit of the use of GPR for the range of rehabilitation and reconstruction practices, pavement structure types, and environmental conditions;
- Provide the MDT with techniques for implementing the results of this study.

C. OBJECTIVES AND BENEFITS

C.1 Objectives

The project's overall objective, as presented in the RFP, is to determine the feasibility of expanding Montana's GPR program used in reconstruction and rehabilitation projects by maximizing the confidence level of the GPR data. The specific objectives required to reach this overall objective, and the steps that we propose to achieve these specific objectives, are listed below:

1. Provide a comprehensive assessment of GPR technologies with regard to current and potential applications to pavement reconstruction and rehabilitation for different pavement structures and environmental conditions. *This assessment has been initiated in Section D.1 of the proposal and will be completed under Tasks 1 through 4 of the program.*

2. Design and conduct a field validation program to characterize the accuracy and confidence levels of the GPR data for different application conditions. *The test program design and conduct are addressed in Tasks 5 and 6. Characterization of accuracy and confidence levels is addressed in Task 7.*
3. Relate the GPR data confidence levels to the reconstruction and rehabilitation decisions scenarios, and use this information to determine which scenarios would and would not benefit from the collection of GPR data. *This analysis is addressed using a sensitivity analysis as described in Task 7.*
4. Provide Montana DOT with a process and procedures for implementing the results of this study. *This objective is addressed via a technical support plan in Task 8.*

C.2 Benefits

This work will benefit MDT by providing a sound, statistical basis for determining when, where, and how its GPR system can be used for determining reconstruction and rehabilitation treatments. In those areas where the GPR system is useful, significant cost savings can be realized by choosing the most economical treatment for the given situation. By identifying where GPR is not useful, the results of this project help the MDT make the most effective use of its time and resources.

D. Description of Research Plan

The paragraphs below describe in detail the elements of the research plan to be carried out under this study.

Phase 1 – Feasibility Study

D.1 Task 1 – Project Initiation and Review of Literature and State of GPR Practice

This task will include a kickoff meeting, a review of literature, a review of current GPR practices by state DOT's, and a review of commercial GPR data analysis software.

Task 1.1 – Kickoff Meeting

The principal investigator, Dr. Ken Maser, will participate in a project kick-off meeting in Helena to meet with the technical panel members and other interested individuals to review and fine-tune the scope, timeline, and expected products of this project. This task will include preparation of the meeting agenda (with input from the State Research Project Manager and Technical Panel Chair), meeting materials, and meeting notes.

Task 1.2 – Literature Review

The objective of this sub-task is to synthesize a comprehensive but concise review of literature dealing with the applications of GPR to pavements. Applications of GPR to pavements have been studied by a number of state, federal, and international agencies over the past 15 years, and specifications for the use of GPR have been prepared by ASTM and by other agencies. Table 1 represents a partial list of studies that will be considered as source material for the proposed literature review. Various universities and research institutions have carried out additional studies. The primary measurement objectives pursued in these studies included pavement thickness, pavement deterioration (eg., stripping), and pavement density or air voids. The application goals of these studies have been for pavement structure evaluation for rehabilitation design, layer thickness evaluation for FWD backcalculation, pavement structure inventories for pavement management systems, and quality control and assurance of new pavement construction.

The value of having local GPR layer thickness data has been studied by Briggs et. al. (1991) and as part of the South Dakota study (Maser, 2006). Based on GPR and FWD data collected on LTPP sites in Texas, Briggs et. al. showed that back-calculated layer moduli using assumed layer thicknesses could be up to 100% in error, and that this error would be substantially reduced using local GPR thickness data. In the South Dakota study, a section on SD 44 was evaluated using the 1993 AASHTO procedure to estimate remaining pavement life. Using the assumed layer thickness from plans (without GPR data), the procedure overestimated the remaining life by approximately 17 percent. The availability of GPR data substantially reduced this error.

Table 1 – Preliminary Review of Published GPR Pavement Studies

Agency	Date of Study	Measurement Objectives	Intended Application	Pavement Type	Ref*	# of Test Sites Reported	Key Findings
Kansas DOT	1991	layer thickness	pavement evaluation	AC	35	14	GPR thickness within 5-10% of cores
Texas DOT	1991, 1992	layer thickness, base moisture	pavement evaluation/ FWD backcalculation	AC	26, 27	13	GPR thickness within 5% of cores
Florida DOT	1991-1997	layer thickness and base material type	pavement management	AC	5, 6	26	GPR can be used for thickness and for distinguishing different types of base materials
Air Force	1992	layer thickness	airfield evaluation	AC & PCC	41	2	GPR thickness within 5% of PCC cores
FHWA	1992	layer thickness	pavement management	AC & PCC	15	4	GPR thickness within 7.5% of cores
FHWA	1996	layer thickness	quality assurance	AC	8	3	GPR can be used for QA
SHRP	1993	pavement deterioration	pavement evaluation	AC	42	3	project did not fully achieve objectives
Wyoming (WTD)	1994	general	pavement evaluation	AC	9	9	GPR thickness within 0.5" of cores
Minnesota DOT	1994	layer thickness	MnROAD Characterization	AC & PCC	14	2	GPR thickness within 2-5% of cores
SHRP	1994	layer thickness	LTTP	AC	21	10	GPR thickness within 5-10% of cores
TRL (UK)	1994	layer thickness	general	AC	11	4	GPR within 10% of cores
Idaho (IDT)	1996	layer thickness	pavement evaluation	AC & PCC	17	6	GPR thickness within 7% of cores
Finnish Rd Admin.	1997	air void	quality assurance	AC	36	tbd	GPR dielectrics provide useful measure of high air void locations
Missouri DOT	1999	layer thickness	quality assurance	AC & PCC	45	4	GPR thickness within 2-5% of cores
Alabama DOT	1999	layer thickness	Pavement management FWD backcalculation	AC	33	3	GPR accuracy sufficient for FWD backcalculation
Arkansas HTD	2000	layer thickness	general	AC & PCC	16	8	GPR thickness agreed with cores
Kentucky DOT	2002	layer thickness	general	AC & PCC	46	8	AC thickness within 0.25" of cores; PCC error is greater
California DOT	2002	layer thickness	quality assurance	AC	23	11	Average GPR thickness within 0.10" of core
FHWA	2003	layer thickness	LTPP	AC		18	GPR data used for LTPP database
Virginia DOT	2004	layer thickness	general	AC & PCC	1	17	GPR accuracy decreases with age for AC pavements
Georgia DOT	2005	stripping	pavement evaluation	AC	7	2	GPR provides screening of possible stripped areas. Other methods needed for verification
Texas DOT	2000-2002	air void	quality assurance	AC	40		GPR dielectrics provide useful measure of high air void locations
North Dakota DOT	2003, 2004	layer thickness	pavement evaluation	AC	13	5	accurate thickness data; occasional problem distinguishing bound from unbound base
South Dakota DOT	2006	layer thickness	pavement evaluation	AC & PCC	19	3	accurate thickness data; used with FWD provides more accurate structure evaluation.

** Reference numbers refer to references listed in Section D.10, "References"*

Table 1 is an example of how we propose to summarize the information to be generated under this sub-task. The material to be reviewed under this task includes references that already exist in Infrasense's comprehensive library of GPR studies, plus other studies accessible through web and TRIS searches. The key information to be sought in each reference is: what types of materials/structures were evaluated; what equipment and analysis procedures were used; what was accomplished; and what limitations were revealed. The sample Table 1 shown here will be expanded to include this additional information, plus the results of additional studies identified in the review.

Task 1.3 – Survey of Current DOT Use of GPR for Pavement Evaluation

The objective of this sub-task is to incorporate information on state DOT use of GPR by direct contact with state highway personnel. For example, as part of South Dakota's project SD-2005-05, Infrasense arranged for a survey to be conducted of state DOT personnel regarding their use of GPR for pavement evaluation. This survey information can be found in that project report, and the results will be incorporated into this task. Table 2 is a preliminary summary of current agency use of GPR for pavement evaluation based on the SDDOT study and subsequent information. As part of this task, this survey will be updated, and state DOT personnel will be contacted to gain further information on current practice and experience with GPR for pavement applications. This subtask will be assigned to NCE, since they are not GPR specialists, and can thus provide a neutral frame of reference for conducting such a survey. A similar approach was used in the SDDOT study. NCE has prepared and performed national surveys on a number of pavement-related topics and possesses multiple contact lists with the appropriate contacts throughout the 50 U.S. State Highway Agencies.

Table 2 – Highway Agency Use of GPR for Pavement Evaluation

AGENCY	NATURE OF APPLICATION	EQUIPMENT OPERATION & DATA ANALYSIS	HISTORY
Texas DOT	Project-level	State forces	over 10 years, numerous projects
Florida DOT	Project and network level	State forces	9 years, numerous projects
Oklahoma DOT	Network thickness	Consultant	3500 miles in 2004, used with FWD
New Jersey DOT	Network thickness	Consultant	1200 miles in 2002
Utah DOT	Network thickness	Consultant	2000 miles in 2004-2005
Missouri DOT	Project level thickness	State University	since 1998
Minnesota DOT	Project level thickness, condition	State forces	since 2000
Michigan DOT	Project level thickness	State forces and consultants	To be reviewed
North Carolina DOT	Project level thickness	State forces	Over 15 years

Task 1.4 – Review of Commercial GPR Analysis Software

It is our understanding that the Montana DOT currently uses GSSI's RADAN© for calculating pavement thickness from the GPR data. However, there are other commercial software packages that are available now or in the near future which may also provide some benefits to MDT's program. Table 3 shows a list of some currently available software programs for GPR data analysis. Organizations that supply this software will be contacted to determine the capability and cost of different software programs, and the software specifications.

Table 3 – Commercial GPR Software

Supplier	Sofware Item	Capabilities
GSSI	Radan	general purpose GPR processing - can use data from other supplier's equipment
	Radan with Pavement Structure Module	adds picking and analysis of pavement layers to Radan
	Radan with BridgeScan	adds bridge deck condition analysis to Radan
Sensors and Software	Conquest 3D	3D imaging of concrete
	Ekko_View	general purpose display and analysis of GPR data
RoadScanners	Haescan	pavement layer thickness
	Road Doctor	adds videologging and georeferencing to above
Penetradar	PavePro	pavement layer analysis
	BridgePro	bridge deck condition analysis

D.2 Task 2 – Review of Montana's GPR Program

As indicated in the RFP, Montana's GPR equipment has been in use since 2006, and the state has gained some experience with the use of this technology. Montana acquired its GPR equipment as part of a combined FWD/GPR system, and we assume that the GPR system has been used in conjunction with the FWD data collection. This application will be evaluated in detail to determine how the two sets of data have been used in combination, and what sorts of data collection and analysis protocols are in place. Collection protocols including data collection parameters and calibration tests (eg., plate reflection test). Analysis protocols including layer picking and layer type interpretation will also be reviewed. In addition, a review of other possible applications of Montana's GPR system will also be carried out as part of this task.

D.3 Task 3 – Documentation of Montana Pavement Structures and Environment

An important first step in this task is to discuss with MDT any anticipated changes related to implementation of the Mechanistic-Empirical Pavement Design Guide (M-E PDG). These discussions could be either face-to-face at the kick-off meeting or through a series of telephone and/or web conferences. Information on the type and age of pavement construction currently in place will have an impact on the effectiveness of GPR. For example, research studies cited in Section D.1 show that the accuracy of GPR data diminishes with pavement age. Thus, for an old pavement that has been recently overlaid, GPR may provide clear overlay thickness data, but the bottom of the old pavement may be less clearly represented. NCE will gather information covering all standard structural designs, rehabilitation guidelines and in-house environmental zones as well as all information available from Montana's pavement management system on in-place pavements.

The usefulness of GPR data may depend on the types of reconstruction and rehabilitation being considered. Therefore, as a part of this task, NCE will review MDT's reconstruction and rehabilitation practices currently in use, and the design procedures and data that are used to support these practices. This information will also be useful for the sensitivity study, as discussed in Task 7.

D.4 Task 4 – Interim Report and Feasibility Assessment

The objective of this task is to review the information developed in Tasks 1-3 and to assess the feasibility of GPR to accurately detect pavement structural layer conditions that have an impact on determining reconstruction and rehabilitation treatments. It is expected that the feasibility will depend on the type of layer condition being detected, the overall pavement construction type, the environmental conditions, and the type of information desired for reconstruction and rehabilitation planning.

At the completion of the feasibility assessment, Infrasense will prepare and submit an interim report summarizing the work of Phase I. After submission of the interim report, the Infrasense Principal Investigator, Dr. Ken Maser, will meet with MDT's technical panel and other concerned individuals to discuss the results of the feasibility assessment and its implications regarding the remainder of the program.

PHASE 2 – FIELD EVALUATION

D.5 Task 5 – Field Testing and Validation Plan

The objective of this task is to develop a field data collection program that provides sufficient data to support the objectives of this project. This program will included GPR data collection, FWD data collection (where appropriate), and core sampling, and will consist of the following subtasks:

Task 5.1 – Design of a Test Matrix

The test program will be based on discussions with MDT personnel, leading to a test matrix that would include the following elements:

1. Pavement structure (eg. thick AC, thin AC, original full depth AC; overlay over original construction, unbound base, cement treated base, bituminous base).
2. AC mix types (conventional binders, PG binders, dense graded, open graded).
3. Environmental conditions (eg. temperature and precipitation).
4. Pavement condition (good, fair, poor).

Test sites satisfying the requirements of the test matrix will be identified in conjunction with MDT staff. Within each test site, a pavement section will be selected for data collection and evaluation. We estimate that the length of the each test section would be on the order of 500 feet. Where possible, LTPP sites will be utilized as part of this study, since these sites are well documented and adjacent areas have already been cored. For example, within the last 2-3 years, coring was performed on the Montana SPS-1, SPS-8 and SPS-9 projects as well as a number of GPS overlay projects. Construction projects where MDT has performed QC coring could be utilized as well. It is estimated that a total of 30 test sections will be required to meet the objectives of this study.

Task 5.2 – Design of Data Collection Plan and Protocol

For each test site, the test plan will specify protocols for GPR data collection, FWD data collection (where appropriate) and the type and location of core samples required for validation of the GPR data. As specified in the RFP, GPR and FWD data will be collected by MDT personnel using the MDT 's equipment. It is understood that MDT 's GPR system utilizes a GSSI Model 4105, 2-GHz horn antenna operated with a SIR-20 GPR data collection and control system. The system is equipped with a DMI so that the rate of data collection (scans per foot) can be controlled. It may be desirable for MDT to consider collection of global positioning system (GPS) data as part of the pavement survey, and the role of GPS will be considered in the test planning.

GPR data collection parameters include scans/foot, time range, and vehicle speed. For FWD testing, MDT typically collects a high density of data (eg. 10 scans per foot) at low speed, localized around each FWD test point. For GPR applications that require continuous layer thickness, data collection is typically carried out at 1 scan per foot at normal driving speed. The one-foot spacing provides adequate level of detail for thickness-based rehabilitation design. Applications that involve local details, such as local damage at joints, require enough data points around the joint to allow it to be fully characterized. For network level application, the data can be aggregated and reported at greater distance intervals. If a GPS system is used, it can operate concurrently with the GPR data collection.

GPS coordinates are recorded on a time base and coordinated with GPR scan locations in the markers database file using RADAN.

The typical time range for the Model 4105 horn antenna is 12 nanoseconds. This range is generally adequate to obtain the thickness of bound layers, and tends to represent the penetration limitations of the antenna. Pavement GPR data is routinely collected at normal driving speeds, and it is expected that data collection on this project will be carried out similarly.

Precise registration of the start and end of each test section is required in order to accurately coordinate the GPR data locations with core locations and other data. This registration can be achieved if the GPR vehicle begins from a stationary position at the start of the test section, and comes to a stop precisely at the end. However, this registration method is not workable for a driving speed survey, or if there is any reasonable amount of traffic. For this type of work, Infrasense uses a photo-reflective optical switch to automatically mark the data when polarized reflective cones are passed. These cones, positioned at the start and end of the test section, indicate the precise location of the start and end of the test section in the GPR data.

D.6 Task 6 – Field Data Collection and Analysis

D.6.1. Data Collection

Dr. Ken Maser, the Infrasense Principal Investigator will coordinate with MDT personnel to arrange for data collection at the sites selected in the test plan, and Infrasense staff will be present during the data collection at these sites. The beginning of each test site will be located with reference to a nearby mile markers or other well-defined reference points such as a bridge joint. The start of each site will be marked with paint, the site length will be measured with a survey wheel, and the end of the site will be marked with paint. GPR data will be collected continuously in one, and possibly both wheelpaths at each site. If FWD data is to be collected, the FWD data locations will be referenced to the start of the test section.

D.6.2. Data Analysis

After data has been collected at all of the test sites, the data will be analyzed by Infrasense staff to determine the pavement structural characteristics that have been defined for each section. A sample of raw GPR data from Montana SPS site 300100 collected in 2003 by Infrasense is shown in Figure 1. This type of data will be processed and presented in graphical and tabular format. A typical graphical format, including core data, is shown in Figure 2.

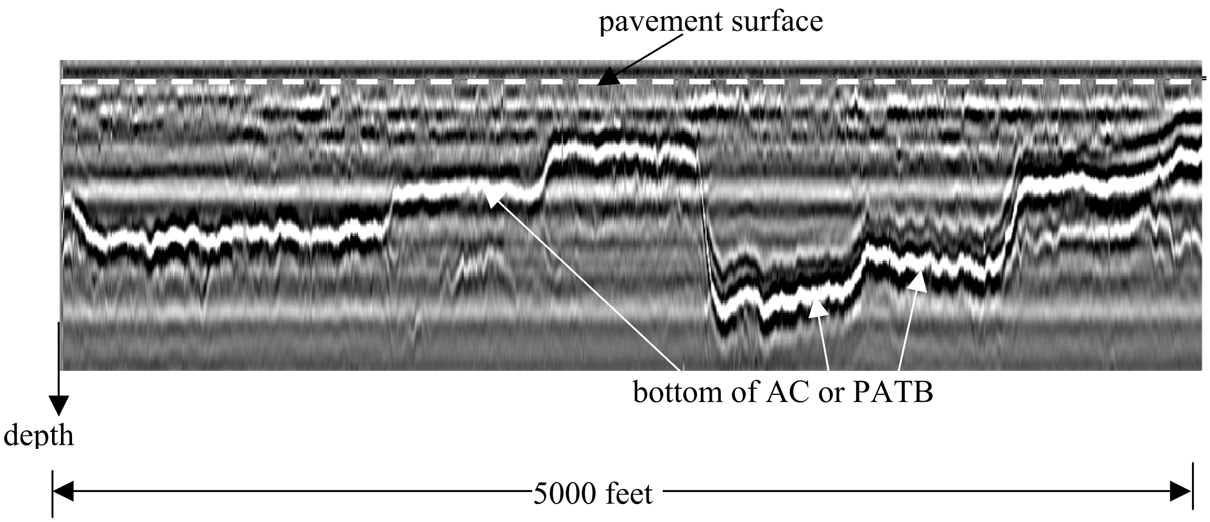

Figure 1 – Raw GPR Data from LTPP Site 300100, Showing Various SPS Sections

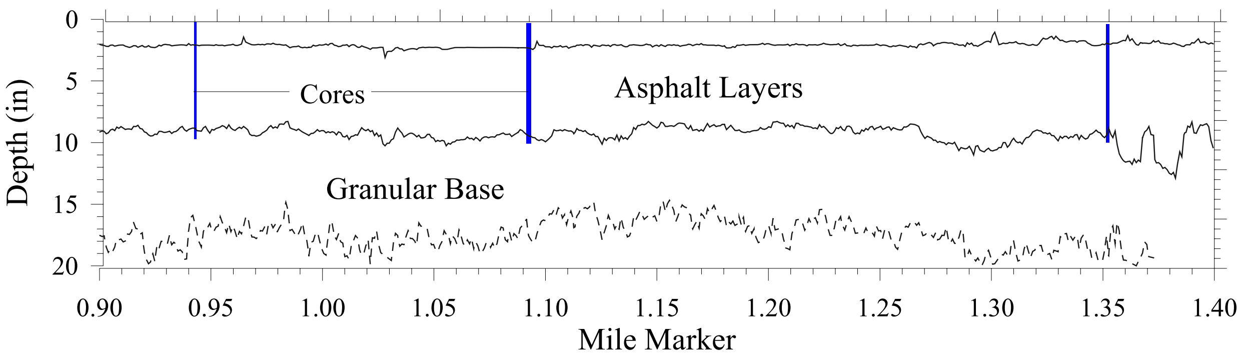

Figure 2 – Sample Plot of GPR Layer Thickness Output

During the data analysis, locations where the GPR data is not clear will be noted. Two types of uncertainty occur during GPR data analysis: (1) uncertainty in layer material type (e.g. multiple layers appear in the GPR data, and it is not clear which of these layers is the boundary between bound and unbound material); and (2) uncertainty in the location of the layer boundary (e.g. the boundary between bound and unbound material is weak or difficult to define). Each of these types of uncertainties will be noted when they occur.

As part of this task, Infrasense will recommend the locations where core data is needed for calibration and layer interpretation. Generally, calibration cores are used to check the internal calibration of the GPR analysis process, and a small number of such cores will suffice. A second category of cores are used to properly interpret layer materials. These cores are useful when there are a number of layers present in the GPR data without a clear indication of which layer separates the bound from unbound material. The availability of cores in such areas will help the layer type identification process. It is understood that all coring operations will be carried out using MDT personnel and equipment.

Where FWD data has been collected, this task will include backcalculation of layer moduli from FWD data using the GPR layer thickness values. This can be accomplished with MDT providing FWD data at established stations along the survey route. Infrasense will have NCE backcalculate the layer moduli using the both the layer thicknesses computed by GPR, and the expected layer thicknesses prior to the GPR survey. The results will be compared, and the impact of having the GPR thicknesses available will be evaluated.

D.6.3 Comparison to Cores

The accuracy of the analyzed GPR data will be determined by correlating the computed layer thickness values to core data which have not been used in the analysis process. Where possible, the test sections will be selected to cover areas where cores have already been taken. Where core data are not available for correlation, Infrasense will recommend locations for coring.

D.7 Task 7 – Data Evaluation and Recommendations

The accuracy and confidence results generated in Task 6 will serve as input to a sensitivity study. The analysis will focus on the impact of variation in GPR data on reconstruction and rehabilitation decisions. For this type of study, the level of confidence in the GPR data needs to be compared to the level of confidence in the knowledge of the pavement structure conditions without the GPR data. Based on these confidence values, the analysis will seek to determine if the addition of the GPR data leads to more appropriate and cost-effective reconstruction and rehabilitation decisions.

Within the last year, MDT published a series of reports regarding “Mechanistic-Empirical Pavement Design Guide Flexible Pavement Performance Prediction Models”. These reports will be studied to establish whether any sensitivity analyses specific to MDT and the M-E PDG have already been carried out. Using this background information, the team will perform a sensitivity analysis on the M-E PDG as related to layer thickness variability, to develop a relationship between GPR variability and the resulting pavement design. The ability of GPR data to quantify layer type and pavement condition will also be taken into consideration for rehabilitation design options.

The results of this analysis will lead to strong conclusions regarding the conditions and scenarios where GPR data collection provides significant benefit to MDT, and where it provides limited or no benefit.

D.8 Task 8 – Technical Support Plan

The objective of this task is to provide the Montana DOT with the technical support resources to implement the results of this study. These include recommendations regarding software and processing procedures, calibration methods, and training. The plan will review the software options currently available to MDT, and will recommend procedures for obtaining the most accurate results using this software. Infrasense has worked extensively with RADAN and with other GPR data analysis software packages. Infrasense has also designed in-house GPR analysis software, so we are very familiar with software issues and are in a strong position to advise the MDT in this area.

Regarding calibration, outside of the normal metal plate and time calibration tests, MDT may wish to consider setting up a thickness calibration slab representing 2 or more pavement layer structures and thicknesses. Testing of this slab can be carried out on a regular basis to ensure that the equipment, and the data collection and analysis procedures, are yielding the known layer structure information within a reasonable tolerance.

As a final part of this task, Dr. Maser, the Infrasense PI, would provide a one-day training session to MDT personnel involved with the operation and use of the GPR system. This session would review data collection, analysis, and interpretation procedures utilized on the project, and more generally the issues that one has to face when working with this type of system. Dr. Maser has over 20 years experience with GPR pavement applications, and he has provided numerous courses, seminars, and training sessions in this field. In order to minimize travel costs, this session will be scheduled to occur during the same time frame as the final project presentation (Task 9).

D.9 Task 9 – Final Report and Presentation

This task will involve preparation of a final report. The report will document all of the work carried out in the project, including the literature review, the review of MDT's GPR program, the documentation of Montana's pavement structures and environment, and the field testing program. The data collection and analysis procedures will be documented, along with a presentation of the analyzed data and the results of the statistical analyses. Final recommendations and the technical support plan will also be documented in the report. A draft report will be submitted to MDT for review. Upon receipt of comments, the report will be finalized and submitted, in the format specified in the RFP.

After submission of the final report, the Principal Investigator, Dr. Ken Maser, will make a formal presentation to the MDT technical panel and other individuals. The presentation will summarize the work described in the final report and will focus on the key findings and recommendations. Dr. Maser has made numerous presentations of this type to state and federal highway agency personnel during his career, including presentations to the SHRP Executive Committee**,** and he has considerable experience to bring to this task.

D.10 Reference Publications

1. Al-Qadi, I. L., Lahouar, S., Jiang, K., McGhee, K., Mokarem, D., “Validation of Ground Penetration Radar Accuracy for Estimating Pavement Layer Thicknesses”, Paper No. 05-2341, *Proceedings, Transportation Research Board 84th Annual Meeting*, Washington, DC, January 9-13, 2005.
2. ASTM D 4748 – 98, “Standard Test Method for Determining the Thickness of Bound Pavement Layers Using Short-Pulse Radar”, Annual Book of ASTM Standards, American Society for Testing and Materials, March, 1998.
3. Briggs, R. C., Scullion, T., and Maser, K. R., “Asphalt Thickness Variation on Texas SHRP Sections and Effect on Backcalculated Moduli” Symposium on NDT and Backcalculation, Nashville, TN, August 1991.
4. Chung, T., and Carter, C. R., “Pavement Thickness Determination and Detection of Pavement Cavities Using Radar”, *Ontario Ministry of Transportation and Communications*, Research and Development Branch, Ontario, Canada, 1991.
5. Fernando, E. G., and Maser, K. R., “Development of a Procedure for the Automated Collection of Flexible Pavement Layer Thicknesses and Material Properties”, Final Report, Florida DOT State Project 99700-7550, 1997.

6. Fernando, E. G., Maser, K. R., and Dietrich, B., "Implementation of Ground Penetrating Radar for Network-Level Pavement Evaluation in Florida", *Proc., GPR '94, Fifth International Conference on Ground Penetrating Radar*, 3, Kitchener, Ontario, Canada, 1994.
7. Hammons, M., Von Quintus, H., Maser, K. and Nazarian, S., "Detection Of Stripping In Hot Mix Asphalt" Final Report, submitted to the Georgia Department of Transportation, Office of Materials and Research, by Applied Research Associates, March, 2005.
8. Hughes, C. S., Simpson, A. L., Cominsky, R., Pendleton, O. J., Weed, R. M., and Wilson, T., "Measurement and Specification of Construction Quality, Volume 2, Final Report", *FHWA Report DTFH61-94-C-00078,* Brent Rauhut Engineering Inc., Austin, TX 78759, 1996.
9. Infrasense, "Applications of Ground Penetrating Radar Applications form Pavement and Bridge Management", Report Submitted to the Wyoming Transportation Commission, January, 1994.
10. Infrasense, "Demonstration of Ground Penetrating Radar for Pavement and Bridge Deck Evaluation", Report Submitted to the North Dakota Department of Transportation, July, 2003.
11. Infrasense, "Evaluation of Road Thickness Measurements at Traffic Speed using Ground Penetrating Radar", Report submitted to the UK Transport Research Laboratory (TRL), February, 1994.
12. Infrasense, "Ground Penetrating Pavement Layer Thickness Survey – Report of Accuracy", Report Submitted to the Kent County Council, UK, February, 1994.
13. Infrasense, "Ground Penetrating Radar Evaluation of Pavements and Bridge Decks", Report Submitted to the North Dakota Department of Transportation, March, 2005.
14. Infrasense, "Ground Penetrating Radar Survey of Pavement Thickness on Mn/ROAD Sections", Report Submitted to the Minnesota Department of Transportation under State Project 72300, November, 1994.
15. Infrasense, "Highway Speed Pavement Thickness Surveys Using Radar", Report Submitted to the FHWA Office of Engineering/Pavement Division, Washington, DC, December, 1992.
16. Infrasense, "The use of Ground Penetrating Radar on In-Service Pavements and Bridge Decks", Final Report, Arkansas Highway and Transportation Department Research Project No. TRC-0102, September, 2001.
17. Infrasense, "Thickness Data Gathering using Ground Penetrating Radar Technology Equipment", Report Submitted to the Idaho Transportation Department, February, 1997.
18. Mallick, R.,B., Maser, K. R., and Nazarian, S., "Guidelines for the Use of Ground Penetrating Radar (GPR) and Portable Seismic Property Analyzer (PSPA) in Full Depth Reclamation Projects" Final Report submitted to the Maine Department of Transportation, April, 2007.
19. Maser, K. R. "Feasibility of using Ground Penetrating Radar (GPR) for Pavements, Utilities, and Bridges" Report SD2005-05 prepared for the South Dakota Department of Transportation, August, 2006.
20. Maser, K. R., "Evaluation of Bridge Decks and Pavements at Highway Speed Using Ground Penetrating Radar," *Proc., SPIE Conference on Nondestructive Evaluation of Aging Infrastructure,* SPIE Publication 2456, Oakland, CA, 1995.
21. Maser, K. R., "Ground Penetrating Radar Studies to Characterize Pavement Layer Thickness Variations at GPS Sites", *Strategic Highway Research Program*, Report SHRP-P-397, 1994.
22. Maser, K. R., "New Technology for Bridge Deck Assessment, Phases I and II", Final Reports. Report No. FHWA-NETC-89-01 and 90-01. Work sponsored by the New England

Transportation Consortium, Center for Construction Research and Education, Massachusetts Institute of Technology. Cambridge, MA, 1990.

23. Maser, K. R., "Non-Destructive Measurement of Pavement Layer Thickness", Report FHWA/CA/OR-2003/03 prepared for the California Department of Transportation, April, 2003.
24. Maser, K. R., "Pavement Characterization Using Ground Penetrating Radar: State of the Art and Current Practice", *Nondestructive Testing of Pavements and Backcalculation of Moduli: Third Volume, ASTM STP 1375,* American Society for Testing and Materials, West Conshohocken, PA, 1999.
25. Maser, K. R., and Mallick, R., " Use of Nondestructive Testing for Detection of Damaged Subsurface Layers in Asphalt Pavements" Proceedings of NDE Conference on Civil Engineering, St. Louis, MO, August 14-18, 2006.
26. Maser, K. R., and Scullion, T., "Automated Pavement Subsurface Profiling Using Radar-Case Studies of Four Experimental Field Sites", *Transportation Research Record 1344,* Transportation Research Board, National Research Council, 1992a.
27. Maser, K. R., and Scullion, T., "Influence of Asphalt Layering and Surface Treatments on Asphalt and Base Layer Thickness Computations using Radar", Te*xas DOTPD Report TX-92-1923-1,* Austin, TX, 1992b.
28. Maser, K. R., and Vandre, B., "Network-Level Pavement Structure Assessment using Automated Processing of Ground Penetrating Radar (GPR) Data" Proceedings of the 2006 Airfield and Highway Pavement Specialty Conference, Atlanta, GA April 30 – May 3, 2006.
29. Maser, K.R., "Bridge Deck Condition Surveys Using Radar: Case Studies of 28 New England Decks", *Transportation Research Record No. 1304*, TRB National Research Council, Washington, D.C., 13-17 Jan., pp. 94-102, 1991.
30. Maser, K.R., "Condition Assessment of Transportation Infrastructure Using Ground Penetrating Radar," *ASCE Journal of Infrastructure Systems,* V.2(2), June, pp. 94-101, 1996.
31. Maser, K.R., Holland, T. J., Roberts, R., and Popovics, J., "Technology for Quality Control of New Pavement Thickness", *Proceedings, International Conference on Non-Destructive Testing in Civil Engineering, NDT/CE*, Berlin, September, 2003.
32. NCHRP, "Ground Penetrating Radar for Evaluation of Subsurface Conditions for Transportation Facilities", *NCHRP Synthesis 255*, Transportation Research Board, National Research Council, 1998.
33. Parker, F., Vecellio, B. and Greene, J., "Evaluation of the Accuracy of Pavement Surface Layer Thickness Measured with Ground Penetrating Radar", Final Report, 930-418 prepared by the Highway Research Center, Auburn University for the Alabama Department of Transportation, October, 1999.
34. Rmeili, E. and Scullion, T., "Detecting Stripping in Asphalt Concrete Layers using Ground Penetrating Radar", Preprint 97-0508, 1997 Annual Meeting of the Transportation Research Board, Washington, DC, 1997.
35. Roddis, W. M. K., Maser, K. R., and Gisi, A. J., "Radar Pavement Thickness Evaluations for Varying Base Conditions", *Transportation Research Record No. 1355*, Transportation Research Board, National Research Council, Washington, DC, 1992.
36. Saarenketo, T. and Roimela, P., "Ground Penetrating Radar Technique in Asphalt Pavement Density Quality Control", *Proceedings of the 7th International Conference on Ground Penetrating Radar*, Lawrence, KS, pp. 461-466, May 27-30, 1998.

37. Saarenketo, T., and Scullion, T., "Ground Penetrating Radar Applications on Roads and Highways", *Texas Transportation Institute Research Report 1923-2F*, 1994.
38. Scullion, T., Servos, S., Ragsdale, J., and Saarenketo, T., "Applications of Ground-Coupled GPR to Pavement Evaluation", *Texas DOT Report 2947-S TX-98/2947-S,* November, 1997.
39. Sebesta, S., Scullion, T., "Using Infrared Imaging and Ground Penetrating Radar to Detect Segregation in Hot Mix Overlays", TTI Report 4126-1, September, 2002.
40. Sebesta, S., Scullion, T., "Application of Infrared Imaging and Ground-Penetrating Radar for Detecting Segregation in Hot-Mix Asphalt Overlays", Paper No. 03-3406 Transportation Research Board, 82nd Annual Meeting, Washington, DC, January 12-16, 2003.
41. Seucy, F.E., Dass, W. C., and Maser, K. R., "Nondestructive Layer Thickness Determination Techniques for and Advanced Pavement System Analyzer Report No. ESL-TR-92-XX", prepared for the Air Force Civil Engineering Support Agency by Applied Research Associates, December, 1992.
42. Smith, S., and Scullion, T., "Development of Ground-Penetrating Radar Equipment for Detecting Pavement Condition for Preventive Maintenance", *Final Report*, Strategic Highway Research Program, Project H-104A, 1993.
43. UK Department of Transport, "Use and Limitations of Ground Penetrating Radar for Pavement Assessment", Design Manual for Roads and Bridges, Volume 7, Section 3, December 1994.
44. Ulriksen, P., "Application of Impulse Radar to Civil Engineering", Doctoral Thesis, Lund Institute of Technology, Sweden, 1982.
45. Wenzlick, J., Scullion, T., and Maser, K.R., "High Accuracy Pavement Thickness Measurement using Ground Penetrating Radar", Report No. RDT 99-003, Missouri Dept. of Transportation, February, 1999.
46. Willet, D., and Rister, B., "Ground Penetrating Radar Pavement Layer Thickness Evaluation", Research Report KTC-02-29/FR101-00-1F, prepared by the Kentucky Transportation Center, December, 2002.
47. Williams, R., T. Martin, K. Maser, McGovern,G., "Evaluation of Network-Level Ground-Penetrating Radar Effectiveness," Paper No. 06-2243, CD-ROM, Transportation Research Board 85th Annual Meeting, Washington, DC, January 11-15, 2004.

E. PRODUCTS

The products of this work will include the following.

1. Quarterly Progress Reports.
2. Phase I Report
3. Draft Final Report
4. Final Report
5. Raw GPR data files collected under this project.
6. Processed GPR data files.
7. An Electronic copy of the Final Presentation.

F. IMPLEMENTATION

The proposed work is intended to provide MDT with a guide to the future use of its GPR system as an aid to selecting reconstruction and rehabilitation treatments. The product of this project, including the GPR accuracy data and sensitivity analyses based on this data, will provide MDT with a means for determining where and under what circumstances their GPR system can play this role. A training session has been proposed that is intended to reinforce the transfer of the knowledge gained from this study into the hands of the Montana DOT, so that it can be implemented in future pavement reconstruction and rehabilitation design.

G. TIME SCHEDULE

Table 5 shows the proposed project schedule. Depending on the project start date, Task 6 (field data collection) will need to be scheduled when weather conditions are suitable. This factor may affect the overall project schedule. The final report task has included time for submission of a draft report and a review cycle of the draft prior to submitting the final.

Table 5 – Proposed Task Time Schedule

Task Month	1	2	3	4	5	6	7	8	9	10	11	12
Phase I												
1. Literature Review	Δ											
2. Review Montana GPR Program												
3. Document Montana Pavement Structures and Environment												
4. Interim Report and Feasibility Assessment			Δ									
Phase II												
5. Field Testing and Validation Plan												
6. Field Data Collection and Analysis												
7. Data Evaluation and Recommendations												
8. Technical Support Plan											Δ	
9. Final Report and Presentation												

Δ = Meetings and Presentations at MDT

H. References (Per Item 4.1.1 of the RFP)

Dr. T. Joe Holland

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Dr. Holland served as Project Manager the following projects carried out by Infrasense for the California Department of Transportation:

1. Non-Destructive Measurement of Pavement Layer Thickness (2000-2003, Contract #65A0074)
2. PPRC Pilot GPR Project – Ground Penetrating Radar Survey in Sacramento and Yolo Counties (2005, project UCPRC-RR-2005/11)

Dan Johnston

Research Engineer
South Dakota Department of Transportation
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Mr. Johnston served as Research Project Manager the following project carried out by Infrasense for the South Dakota Department of Transportation:

1. "Feasibility of using Ground Penetrating Radar (GPR) for Pavements, Utilities, and Bridges", (2005-2006, SDDOT Project SD2005-05)

Bruce Vandre

Pavement Evaluation Engineer (Retired)
Utah Department of Transportation
1591 East 10 South
St George, UT 84790
Phone: 801-965-4835
Email: bvandre@aol.com

Mr. Vandre served as Project Manager the following project carried out by Infrasense for the Utah Department of Transportation:

1. “Pavement Thickness Surveys (1900 Lane Miles)”, (2004-2005, UDOT Project 02-9200)

I. STAFFING

The project team combines the resources and personnel from Infrasense, Inc. and Nichols Consulting Engineers, Ltd. (NCE). Infrasense provides 20 years of expertise and experience with GPR applications to pavements. NCE, which has been collecting and analyzing performance data—including FWD and pavement condition—throughout the Western United States since 1990, possesses unique expertise to relate the GPR and other data to reconstruction and rehabilitation design applications.

The principal investigator is Dr. Kenneth Maser of Infrasense, an internationally recognized expert in the application of GPR to highway structures. Dr. Maser will be supported at Infrasense by Laura McGrath and Beth Miller, both of whom represent over 20 years of experience with GPR pavement data collection, processing and interpretation. The Infrasense team will be supported by Mr. Kevin Senn and Mr. Jason Puccinelli from NCE, whose pavement expertise will primarily be utilized in Tasks 3, 5, 6 and 7. Both Mr. Senn and Mr. Puccinelli have over 10 years of experience with data collection in Montana and 13 other Western Highway Agencies as part of the LTPP Program, as well as extensive pavement design experience.

The following sections describe the key organizations and key individuals in greater detail.

I.1 BACKGROUND OF KEY PARTICIPANTS

I.1.1 INFRASENSE, INC.

Dr. Kenneth Maser, PE – Infrasense Principal Investigator

Dr. Maser will supervise and coordinate all aspects of the program. Dr. Maser is an internationally recognized authority in the field of nondestructive evaluation of structures and construction materials, with a particular emphasis on GPR. He has developed and put into practice techniques for bridge and pavement evaluation and is the holder of two U.S. patents. He has also taught graduate-level courses in nondestructive evaluation during his affiliation with the Massachusetts Institute of Technology (MIT), Civil Engineering Department, and has served on the continuing education Faculty of the University of Wisconsin, teaching courses in GPR. Throughout his career he has managed numerous research, development, evaluation, and service programs, with budgets ranging from $20,000 to $2,000,000.

Since 1987, Dr. Maser has supervised GPR pavement and bridge deck surveys on over 18,000 lane miles of pavements and over 800 bridge decks. He has tested and utilized all types of GPR equipment and software, including all manufactured horn antenna systems. He has developed GPR analysis software for pavement and bridge deck evaluation, and he has conducted numerous evaluation studies to establish and validate the accuracy and reliability of GPR-based pavement thickness and bridge deck condition evaluations. He has supervised these studies for a number of agencies, including the New England Transportation Consortium (1987-1989), TxDOT (1990-1991), New Hampshire DOT (1990), Kansas DOT (1991), Wyoming Transportation Department (1994), MnROAD (1994), Idaho Transportation Department (1996), Arkansas SHTA (2001), SHRP (1992), LTPP (2003), FHWA (1992), UK Transport Research Lab (1994), and Caltrans (2003). He has also contributed to GPR evaluation studies directed by other organizations including the Alabama DOT, the NCHRP, the Florida DOT, and the USAF.

Dr. Maser served for 4 years as a consultant to the Strategic Highway Research Program (SHRP) for the development of equipment and data interpretation methods to evaluate delamination and deterioration in asphalt and concrete pavement. The methods developed represented a combination of ground penetrating radar, impulse response, impact echo, ultrasonic wave velocity and spectral analysis of surface waves (SASW). Dr. Maser advised SHRP on all aspects of the project, recommended testing and evaluation procedures and reviewed all results.

Dr. Maser is the author of over 100 numerous technical articles and publications on the subject of sensors for the evaluation of constructed facilities. A number of these references are cited in the bibliography presented in the Research Plan, Section D.10. Dr. Maser was formerly a member of the ACI #228, Committee on Non-Destructive Testing, where he helped prepare application specifications for GPR and Infrared Thermography. Presently Dr. Maser is an Associate Editor of the ASCE Journal of Infrastructure Systems.

Laura McGrath – Infrasense Senior Data Analysis Engineer

Ms. McGrath will assist Dr. Maser with GPR data analysis and interpretation for the field test sites and with statistical evaluation of the GPR vs. core data. MDT. Employed with Infrasense since 1995, Laura McGrath is a specialist in the analysis of GPR field data and software development. She holds a BS Degree in Computer Science and an MS degree in Civil Engineering (Geotechnical). She has been responsible for GPR data analysis on over 2000 lane miles of pavement. She has also been responsible for both in-house and external ground penetrating radar (GPR) data analysis software development for the interpretation of GPR field data collected on pavements and bridge decks. Her specific areas of experience are summarized below:

Ms. McGrath has handled many GPR bridge deck and pavement data analysis applications, and her analytical skills give her a unique specialty in with large complex structures. For example, she has handled the GPR data analysis for the 3-mile long Tappan Zee Bridge over the Hudson River (1.3 Million sq. ft. – 2003)) and the Rouge River Bridge in Detroit (2 million sq.ft –2001). As part of a FHWA research project, she was involved with the analysis of complex strain, displacement, and rotation data patterns collected on bridge substructures in order to identify unknown foundations (1999).

In the software development area, she developed PAVLAYER software, an Infrasense in-house application to analyze pavement condition and thickness. Program development included user interface, graphical presentation, matrix processing, and the production of training materials and a user's guide. The system was used to conduct a statewide assessment of pavement condition. Under an NCHRP Project (NCHRP IDEA-61, 2000), she developed automated software for quality assurance of new pavement construction using a GPR system. The implemented software package combining GPR processing algorithms, a graphical user interface, and a post-processing data presentation so that a technician can carry out the analysis in the field. This software is now being evaluated by Infrasense under a current NCHRP Project (10-65), *"Nondestructive Testing Technology for Quality Control and Acceptance of Flexible Pavement Construction."*

As part of a Caltrans contract through the University of California at Berkeley (2000), Ms. McGrath developed analytic procedures and software for integrating GPR thickness data, highway traffic patterns and weather data into cracking and rutting models developed by UC Berkeley.

Beth C. Miller, PE – Infrasense Project Engineer

Beth C. Miller joined Infrasense in 2000 and has focused on the collection and analysis of GPR data on pavements and bridge decks, and for geotechnical studies of existing infrastructure facilities. Ms. Miller has conducted GPR analysis of over 1000 lane miles of pavement. She was responsible for GPR data collection at 19 LTPP test sites distributed throughout the US (2003), and for 600 lane miles of data collection in California (2005).

Ms. Miller earned a Masters of Science in Civil Engineering from the University of Wisconsin, Madison, WI in 2000 studying Infrastructure Management, and a Bachelor of Science in Civil Engineering from the University of Michigan, Ann Arbor, MI in 1981. Prior to graduate school, she was a project engineer in the City of Detroit for $20 million/year of road reconstruction and rehabilitation projects, where she streamlined inspection reporting requirements to handle an increased workload without an increase in staffing.

I.1.2 NICHOLS CONSULTING ENGINEERS (NCE)

Kevin Senn, NCE – Project Manager

Mr. Kevin Senn, P.E. heads the Research Department at NCE and has over 13 years of experience in pavement design, materials, construction, highway research, performance monitoring, database management and design, and Weigh-In-Motion evaluation and calibration. Mr. Senn has served as the Project Manager the Long Term Pavement Performance Western Regional contract since 2003, and continues important work on the LTPP Data Analysis contract. NCE has been awarded ten Task Orders on the data analysis work, including performance modeling and environmental impacts on pavement performance. Mr. Senn was also the Project Manager on an Arizona DOT contract to develop a new ESAL design table for Arizona's highway system. This project involved assimilating LTPP and non-LTPP traffic information throughout Arizona and creating an interactive database to predict cumulative loading at over 1000 traffic segments comprising over 7000 lane miles. The project was completed on-time, within budget, and to the complete satisfaction of the client. Mr. Senn is currently serving as the Project Manager for an On Call contract for the Arizona DOT. Activities to date include pavement evaluation and analysis, materials specification investigation, and pavement noise monitoring.

Mr. Senn has been and continues to be involved in a wide range of research, pavement design, materials and performance monitoring projects, which also include performing the finite element analysis that allowed NCE to develop a new rebar configuration on Utah DOT's multi-billion dollar I-15 design-build project. Mr. Senn is currently an active member of TRB Committee AFD20 "Pavement Monitoring, Evaluation and Data Storage" and has presented LTPP information to various audiences, including the Nevada Infrastructure Concrete Conference, WASHTO-X and Highway Agencies throughout the Western United States.

Mr. Senn has developed excellent working relationships with State Highway Agencies and Industry Representatives. These relationships coupled with his pavement research experience will provide great benefit to the proposed research team.

Jason Puccinelli, NCE – Project Engineer

Mr. Jason Puccinelli has been working in the Research Department at NCE for ten years and is currently serving as the Quality Control and Quality Assurance (QC/QA) Manager for the Long Term Pavement Performance (LTPP) program and as a key research engineer on multiple studies as part of the LTPP Data Analysis project. He has been heavily involved in most of the task orders and coordinated the statistical studies preformed on the Frost Effects on Pavement Performance study. As the QC/QA Manager, he is responsible for developing and implementing procedures that ensure compliance with LTPP guidelines. This includes regular reviews of the field data collection and office data processing procedures, documentation of the findings, compilation of review reports, and follow-up reviews to document the implementation and effectiveness of corrective actions. Mr. Puccinelli also is the main point of contact for eight agencies participating in the LTPP program, including Montana DOT. Through this capacity he and NCE have developed close working relationships with the other agencies, ensuring excellent communication and cooperation on matters affecting the LTPP program. This coordination facilitates the acquisition and verification of data, and resolutions of any issues regarding rehabilitation and maintenance activities performed on LTPP test sections.

For several years, Mr. Puccinelli has also acted as the Distress Coordinator for the Western Regional Support Contract, where he is responsible for all aspects of distress data including collection schedule, training new surveyors using the LTPP Distress Identification Manual (FHWA-RD-03-31), quality control, and coordinating with FHWA and other Regional Support Contractors to ensure distress data is being collected in accordance with established guidelines.

Mr. Puccinelli has also conducted numerous pavement design projects for cities and counties in Northern California. In this capacity, he has coordinated field data collection activities, analyzed the information, and provided design recommendations based on the findings. Projects include many renewal projects including a design-build project on I-15 in Las Vegas where the recommended renewal strategy was rubblization of existing JPCP with an HMA overlay.

I.2 Related Accomplishments of the Research Team

I.2 1 Infrasense Accomplishments

Table 6 highlights representative past Infrasense accomplishments in areas relevant to the proposed program. Dr. Maser was personally responsible for all of these projects.

Table 6 – Summary of Infrasense Accomplishments in Areas Relevant to the Proposed Program

PROJECT	AREA OF RELEVANCE	DESCRIPTION	CONTACT
Hawaii DOT Demonstration and Training (2007)	GPR Pavement Thickness evaluation and technical support	Provided demonstration of thickness evaluation on 6 pavements and training of DOT Personnel	Loy Kuo, HDOT 808-832-3405
New Hampshire I-93 Survey (2007)	GPR Pavement Thickness Evaluation	Thickness evaluation of 130 lane miles of pavement	Eric Thibodeau, NHDOT 603-271-1750
South Dakota GPR Study (2005-2006)	Application of GPR to Pavement Thickness Evaluation	Complete feasibility study, evaluation of test sections, correlation with cores and FWD data	Dan Johnston, SDDOT 605-773-5030
Caltrans PPRC Pilot GPR Project (2005)	Application of GPR to Network Pavement Structure Assessment	Survey of 600 lane miles. Evaluation of layer thickness and correlation with cores	T. Joe Holland, CALTRANS 916-227-5825
Utah Network GPR Survey (2004-2005)	Application of GPR to Pavement Management	Pavement structure evaluation of 1900 lane mile. Provided RADAN training to UDOT personnel	Bruce Vandre, UDOT 801-965-4835
North Dakota GPR Studies (2003-2005)	GPR technology evaluation: Application of GPR to bridge decks and pavements	Surveyed 6 pavement sections and 5 bridge decks. Results compared to cores and other methods	Bryon Fuchs, NDDOT 701-328-6903
Georgia Stripping Study (2005-2007)	Application of GPR to detection of moisture damage in AC	Methodology developed for detection of moisture damage using GPR, PSPA, and tests on cores. Tested on I-20 and I-75/85	Mike Hammonds, ARA 353-514-6429
LTPP SPS-1 Survey (2003)	Application of GPR to the performance assessment of pavement research sites	Surveyed approximately 200 LTPP sections at 19 Sites nationwide	Jack Springer, FHWA 202-493-3144
Caltrans Thickness QA Study (2000-2003)	Technology evaluation: application of GPR for QA of asphalt thickness	Developed methodology and applied it to 11 sites in California. Results correlated with cores	T. Joe Holland, CALTRANS 916-227-5825

Table 6, *continued*
Summary of Infrasense Accomplishments in Areas Relevant to the Proposed Program

PROJECT	AREA OF RELEVANCE	DESCRIPTION	CONTACT
NCHRP 10-65 (2003-2007)	Application of GPR to QA/QC of New Pavement Construction	3 construction sites surveyed with GPR – Lift thickness and air void calculated and compared to cores	Harold von Quintus, ARA 512-218-5088
Arkansas SHTD (2001)	GPR Technology evaluation: Application of GPR to bridge decks and pavements	Surveyed 6 pavement sections and 5 bridge decks. Results compared to cores	Alan Meadors, ASHTD 501-569-2103
Michigan Pavement Thickness Evaluation – Districts 3 and 4 (1996)	Application of GPR for Layer Thickness on Recycle Projects	118 lane miles of rural interstates and primary roads surveyed for layer thickness	Dave Smiley, Michigan DOT Pavement Management Unit 517-322-1766
Grand Central Parkway, New York City (2002)	Application of GPR on Overlaid Concrete Pavement for Overlay Thickness and Concrete Condition	Surveyed 80 lane miles of urban parkway in New York City. Provided layer thickness and repair quantity estimates	Barney LaGreca, Daniel Frankfurt Engineers, P.C. 212-689-9400x331
Illinois State Toll Highway Authority (ISTHA) Evaluation (2002)	Application of GPR on Overlaid Concrete Pavement for Overlay Thickness and Concrete Condition	Surveyed 450 lane miles of urban interstate highway in the Chicago area. GPR thickness data correlated to cores	George Knobloch, Consoertownsend Envirodyne Engineers, Inc. 630-241-6800 x3963

I.2 2 NCE Accomplishments

Table 7 – Summary of NCE Accomplishments in Areas Relevant to the Proposed Program

PROJECT TITLE RELEVANCE	CLIENT AND CONTACT	DESCRIPTION / SUMMARY
Long Term Pavement Performance (LTPP) Western Regional Support Contract	Federal Highway Administration Mr. Jack Springer FHWA-LTPP COTR (202) 493-3144	Western Regional Contractor since 1990 covering five contracts totaling over $25,000,000 that were competitively awarded. NCE's responsibilities include field date collection, database management, analysis, and data submissions.
Long Term Pavement Performance Data Analysis Support Contract	Federal Highway Administration Mr. Larry Wiser FHWA-LTPP COTR (202) 493-3079	NCE has been awarded ten task orders under this contract including assessment and coordination of LTPP data, optimization of traffic data, evaluation of the effects of moisture and freeze cycles, and computed parameter: dynamic modulus.
Development of New Pavement Design Equivalent Single Axle Load	Arizona Dept of Transportation Estomih Kombe, Ph.D., P.E. Arizona Department of Transportation Research Center Phoenix, Arizona (602) 712-3135	NCE performed a study to prepare a new ESAL design table for Arizona's Highway Network, which consisted of over 7000 centerline miles. This new table is based on analysis of current traffic data collection procedures, traffic forecasting methodology, and ESAL development procedures, including the assignment of traffic ESAL levels for any time-interval specified by the designer to over 1000 highway segments.
WesTrack Experimental Road Test Facility	Federal Highway Administration Terry Mitchell, PhD, PE Federal Highway Administration (202) 493-3147	Work on the project included all phases from conception to the final reports. The experiment was designed with topographic and geometric mapping of the site, detailed construction plan was developed, specialized materials were summarized, and quality control and quality assurance (QC/QA) procedures were incorporated.
California State-wide Roads and Streets Assessment	County Engineers Association of California (CEAC) Greg Kelley, Assistant Deputy Director Los Angeles County Public Works Geotechnical and Materials Engineering Division (626) 458-4911	Statewide needs assessment study of 536 cities and counties in California. This study of over 137,000 miles of local streets and roads will evaluate pavement and non-pavement inventory, determine the condition of local streets and roads, project future needs to maintain (or improve) their condition; and compare "needs" to projected revenue.

Table 7 – *continued*
Summary of NCE Accomplishments in Areas Relevant to the Proposed Program

PROJECT TITLE RELEVANCE	CLIENT AND CONTACT	DESCRIPTION / SUMMARY
Pavement Management Systems	Over 200 agencies including the Cities of Fremont, San Jose, Mission Viejo, and Mono County, California, along with work done nationally and internationally	NCE's staff includes experienced pavement management specialists who help agencies implement, update and operate pavement management systems and to develop reasonable maintenance and rehabilitation plans.
Pavement Designs	Multiple agencies across the Western United States	NCE provides pavement designs and construction management and inspection services to local and state clients, ensuring that projects are built in accordance with applicable contract documents and permit requirements.

I.3 Breakdown of Person-hours by Task

Table 8 – Proposed Breakdown of Person-hours by Task

Name of Principal Professional or Support Classifications	Role in Study	Tasks									Total
		1	2	3	4	5	6	7	8	9	
Infrasense											
K. Maser	Principal Investigator	55	43	4	24	40	63	24	24	67	344
L. McGrath	data analysis						120	24			144
B. Miller	field testing representative						60				60
Staff Engineer	literature review/data analysis	40					80				120
Office Mgr.	prepare/edit documents	8			8					16	32
NCE											
K. Senn	Agency surveys, cost benefit analysis	4		20	4	20	8	20	0	8	84
J. Puccinelli	Agency surveys, cost benefit analysis	24		40	8	40	40	40	0	16	208
Technician	field data analysis	0		0	0	0	32	0	0	0	32
Admin Support	prepare/edit documents	2		4	0	0	0	12	0	4	22
TOTALS		133	43	68	44	100	403	120	24	111	1046

J. FACILITIES

J.1 Infrasense Facilities

GPR Equipment

Infrasense owns and operates a FCC approved SIR-20 GPR system and a GSSI Model 4108 1.0 GHz GPR horn antenna. The antenna and GPR system operate from a survey vehicle. This setup includes an electronic distance measurement encoder attached to the vehicle wheel for recording distance, and a Trimble AG114 GPS unit. The GPS unit records coordinates simultaneously with the GPR data collection, and the GPS coordinates are tied in to the GPR scan number. The setup also includes two types of antenna mounting systems – one for pavement surveys (centerline position) and one for bridge deck surveys for movable antenna positioning.

Infrasense also owns and operates a laser-based photo-reflective optical switch that automatically marks the start and end of pavement sections while the survey vehicle is traveling at normal driving speed.

GPR Analysis Software

Infrasense has developed and currently utilizes PAVLAYER® and DECAR®, advanced data processing programs for analysis and interpretation of GPR pavement and bridge deck data. With input from the operator, the software automatically progresses through all of the GPR scans, locates the relevant interfaces in the data and calculates layer thicknesses, the layer dielectric permittivities, rebar depths, and layer reflection amplitudes for deterioration analysis. The software produces output in Excel and database compatible formats, as well as in graphic compatible formats for line plots, contour plots, and CADD compatibility. Infrasense also has a fully automated version of PAVLAYER for on site processing of pavement thickness and air voids for QA of new pavement construction.

Infrasense also has licensed copies of GSSI's RADAN software, a general purpose GPR data processing program, and RADAN's Road Structure Analysis Module.

J.2 NCE Facilities

Equipment

NCE's field equipment is state-of-the-art, owning and operating a Dynatest 8000 Falling Weight Deflectometer (FWD) for nondestructive pavement investigation and evaluation. This unit has been calibrated to current LTPP standards. In addition to pavement deflection testing, NCE provides a wide range of field data collection services including materials sampling, distress surveys, and performance evaluation. NCE's equipment includes high-powered coring equipment that can aid in pavement sampling operations. The company also maintains and operates government-owned Dynatest FWDs, K.J. Law Profilometer, Dipstick, Faultmeter, and pavement instrumentation equipment.

Software

NCE is well equipped with a variety of up-to-date software packages, including engineering, statistical analysis, CAD, ESRI, spreadsheet, word processing presentation, programming, communication, and others. The firm's staff is well trained and highly knowledgeable on all relevant computer software. This expertise coupled with the extensive transportation publication library available to the staff allows NCE to use the latest research, analysis, and design techniques in serving its clients and delivering valuable information. NCE also maintains electronic communication media for fast information delivery to its clients and others. With this capability, NCE produces professional reports, customized analysis, and presentations for a variety of needs.

K. MDT Involvement

The following areas of MDT involvement are anticipated:

1. Provide information and data on Montana's GPR program
2. Provide data on Montana's pavement structure types, environmental conditions, and reconstruction and rehabilitation policies and methods
3. Assist in the selection of sites for field testing
4. Provide GPR and FWD equipment and operator for field tests
5. Collect core data on tested pavement sections